REMARKS

Claims 1-24 are currently pending in the above-identified patent application. In the Office Action dated November 13, 2003, made final, claims 1-3, 5, 6 and 8-13 were rejected under 35 U.S.C. 103(a) as being unpatentable over applicant's admissions of prior art in view of Czubatyj et al. (U.S. Pat. No. 4,419,533), and claims 4, 7, 14, and 15-24 were rejected under 35 U.S.C. 103(a) as being unpatentable over applicant's admission of prior art in view of Czubatyj et al. in combination with other references.

In the Examiner's Response to Arguments, directed to applicant's Amendment C filed on September 29, 2003, the Examiner stated that "Applicant has argued that the teachings of Czubatyj et al. differ from the instant invention because Czubatyj et al. only use the gratings to enhance the absorption at the band edge. ... In regard to Applicant's arguments based on Czubatyj et al.'s use of gratings only to enhance the absorption of the band edge, it is noted that the instant claims do not include limitations relating to the wavelengths whose absorption is increased. Since Czubatyj et al. teach at least the increased absorption of the longer wavelengths and the total absorption of substantially all of the shorter wavelengths on the first pass, the reference is deemed to teach a method for increasing absorption of light radiation. It is further noted that Czubatyj et al. teach the desirability of 'substantially total absorption while assuring more complete collection of the electron-hole pairs'. ... The teaching of Czubatyj et al. leads to the same result as Applicant's claimed method. By directing incident radiation through the active region at angles at least greater than the critical angle, the absorption of light close to the surface would be enhanced in comparison to undirected incident radiation. ..."

Applicant wishes to thank the Examiner for the helpful suggestions in setting forth the teachings of Czubatyj et al., and has amended claims 1, 15 and 20 and canceled claims 3 to more clearly distinguish the present invention from that of Czubatyj et al. Support for the amendment of claims 1, 15 and 20 for limiting the photo responsive device to crystalline silicon derives from canceled claim 3, as originally filed and the discussion in the present Specification, as originally filed, on

page 12, lines 11-19. Moreover, it is known that the band edge for crystalline silicon is approximately 1.1 μm. Therefore, no new matter has been added by these changes.

Reexamination and reconsideration are respectfully requested.

Turning now to the rejection of all claims under 35 U.S.C. 103(a) as being unpatentable over Czubatyj et al. in combination with other references, in Col. 15, lines 42-49, Czubatyj et al. states: "The incident light directing means **172** comprises a transmission diffraction grating **178** arranged to direct all of the incident light through the intrinsic region **180** at an angle. However, since nearly all of the shorter wavelength light will be absorbed in the intrinsic region **180** during the first pass, the diffraction grating **178** can be optimized for the longer wavelengths as previously described." Further, in Col. 15, lines 13-18 Czubatyj et al. states: "First order diffraction is also enhanced when d is about equal to a wavelength at the frequency of interest. Here, because most of the shorter wavelength photons are absorbed in the active intrinsic region **160** during their first pass, the longer wavelength photons of about 6600 Å and longer are of interest." Therefore, according to Czubatyj et al., the best first-order diffraction is achieved when the grating period is equal to the wavelength of interest. For amorphous silicon (Si) thin films, the band gap is at wavelength (λ) of 0.66 μm, so the grating period (d) is chosen to be 0.66 μm. At normal incidence with $\lambda/d = 1$, and diffraction order $n = \pm 1$, the diffraction order angle is determined to be θ_c at normal incidence in their material system consisting of indium tin oxide ($n = 2.1$) and amorphous Si ($n = 3.5$). For all wavelengths below 0.66 μm, the diffraction orders propagate at angles less than θ_c, and will escape through the front surface after the first pass.

As is described hereinbelow, if a grating period of 1.1 μm is selected to match the band edge at 1.1-μm for crystalline silicon photovoltaic devices as recited in the present claimed invention, for normal incidence on a transparent grating formed on a Si substrate having a refractive index of 3.5, for $\lambda = d = 1.1$ μm, the angles of the ± 1 transmitted orders are ± 16.6°. For shorter wavelengths; that is for $\lambda = 1.0$, 0.9, and 0.8 μm, as examples, the respective angles of ± 1 transmitted

orders are ± 15.05°, ± 13.52 °, and ± 12.0°, respectively; all are less than the critical angle, θ_c. Therefore, the grating behaves as if it were a planar surface, and a transparent front surface grating will not perform in accordance with the teachings of the present claimed invention; that is the selection of a grating period of 1.1 μm to match the band edge at 1.1 μm for the crystalline silicon photovoltaic devices taught by the present claimed invention does not result in the claimed transmitted orders having angles greater than the critical angle as is required by independent claims 1, 15 and 20.

Figures 1 through 4, hereinbelow are graphs of the measured internal quantum efficiency (IQE) solar cells having gratings with periods between ~ 0.3 and 1.0 μm as a function of incident wavelength; otherwise, the gratings were fabricated in a similar fashion. To be noticed is: (1) The best long-wavelength response is achieved at periods of ~ 0.5 μm and ~ 0.8 μm; (2) The poorest long-wavelength response is observed at periods of ~ 0.3 μm and ~ 1.0 μm; (3) The IQE enhancement for periods of ~ 0.5 μm and ~ 0.8 μm peaks at λ ~ 1.0 μm; and (4) The IQE enhancement for periods of ~ 0.5 μm and ~ 0.8 μm peaks has a broad range varying from λ ~ 0.55 μm to λ ~ 1.15 μm.

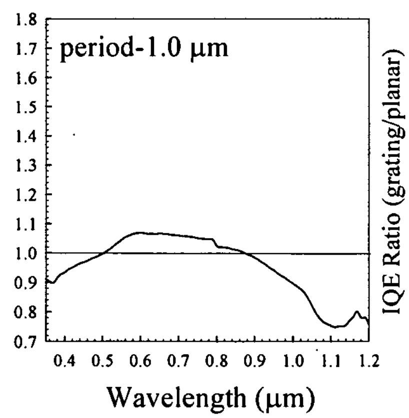

Figure 1. Internal Quantum Efficiency Ratio for Solar Cells having a Grating with ~ 1.0 μm Period.

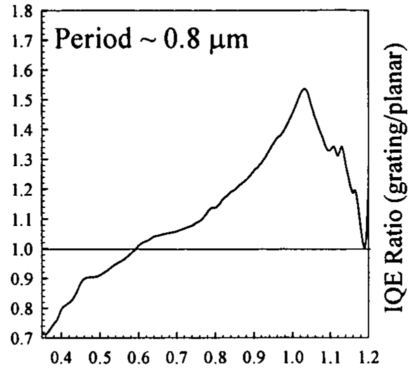

Figure 2. Internal Quantum Efficiency Ratio for Solar Cells having a Grating with ~ 0.8 μm Period.

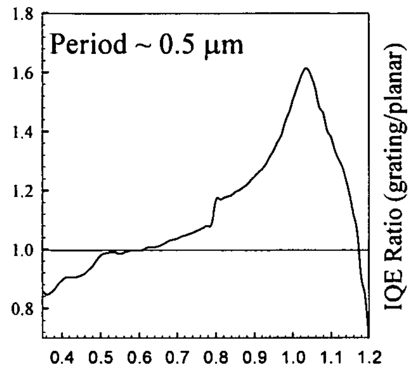

Figure 3. Internal Quantum Efficiency Ratio for Solar Cells having a Grating with ~ 0.5 μm Period.

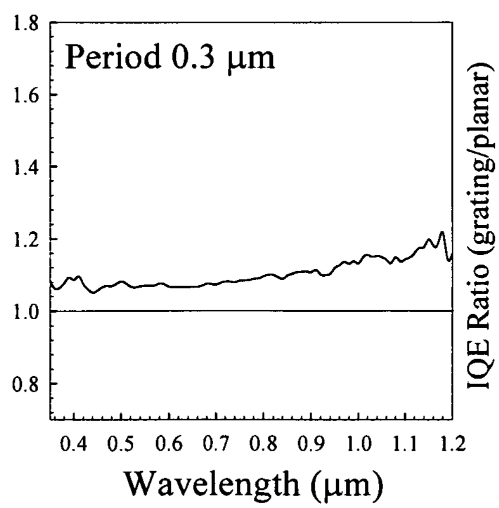

Figure 4. Internal Quantum Efficiency Ratio for Solar Cells having a Grating with ~ 0.3 μm Period.

The IQE enhancement for wavelengths less than 1.1 μm has been described in detail in the present Specification. Basically, for grating periods of 0.5 μm and

0.8 μm, the generated ±1, ±2, and ±3 diffraction orders propagate at angles greater than θ_c as shown in Tables 1 and 2 for normal incidence light.

Table 1: Diffraction Angle Distribution for a 0.5 μm Period.

Wavelength (μm)	First order diffraction Angles (±1)	Second Order diffraction Angles (±2)
0.8	27.2	66.1
0.9	30.95	> 90
1.0	34.85	> 90
1.1	38.9	> 90

Table 2: Diffraction Angle Distribution for a 0.8 μm Period.

Wavelength (μm)	First order diffraction Angles (±1)	Second Order diffraction Angles (±2)	Third Order diffraction Angles (±3)
0.8	16.6	34.85	59
0.9	18.75	40	74.64
1.0	20.93	45.58	> 90
1.1	23.13	51.77	> 90

The enhancement of the present invention in the wavelength region below about 1.1 μm can only be explained by diffractive scattering greater than the critical angle, θ_c. By creating many obliquely propagating diffraction orders, electron-hole pairs are generated closer to the front surface when compared with those for a refractive surface. By reducing bulk recombination losses, the IQE is enhanced.

This is unimportant according to the teachings of Czubatyj et al. since short wavelengths are absorbed within the same thickness due to the strong absorption of direct band gap structure. Therefore, using the grating teachings of Czubatyj et al. does not allow the present invention to perform as intended; rather, poor results would be obtained for indirect band gap crystalline solar photovoltaic devices.

Moreover, although Czubatyj et al. teaches away from the use of crystalline silicon due to its poor optical absorption, it can be argued that that invention of Czubatyj et al. is not limited to amorphous silicon. As shown hereinabove, if one applies the teachings of Czubatyj et al. to a thin film crystalline configuration (grating period of 1.1 μm) optical losses increase and a poor photovoltaic device results due to the escape of shorter wavelengths.

For these reasons, applicant respectfully believes that the Czubatyj et al. reference teaches away from the subject claimed invention and, therefore, has been improperly combined with the references identified by the Examiner in the rejection

of all pending claims under 35 U.S.C. 103(a). The Examiner has therefore failed to make a *prima facie* case for an obviousness-type rejection.

Therefore, applicant believes that claims 1-24, as amended, are in condition for allowance or appeal and the former action by the Examiner at an early date is earnestly solicited. Reexamination and reconsideration are respectfully requested.

Respectfully submitted,

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Signature of Attorney

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